OPTIMAL DESIGN OF PASSIVE POWER FILTERS USING GENETIC ALGORITHM

FAIZ MUHAMMD

A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical-Power)

Faculty of Electrical Engineering
Universiti Tecknologi Malaysia

JUNE 2015

To My Parents

ACKNOWLEDGEMENT

I am indeed grateful to Almighty Allah for providing me opportunity and strength to commence and conclude my Master of Engineering at university technology Malaysia

I would like to express my heart-felt gratitude to my supervisor Honourable Madam Dr Dalila Bt Mat Said for her inspirational guidance and excellent supervision and encouragement throughout the duration of my work.

I wish to express my sincere appreciation to the faculty members Dr Mohd Junaidi Bin Abdul Aziz, Associate Professor Dr Azhar Bin Khairuddin and Dr Md Pauzi Bin Abdullah for their valuable contributions during my course work

I should not forget to appreciate the encouragement and support received from my father Professor Mueendin from department of electrical and electronic engineering and other family members. I also would like to appreciate all those that have helped me directly or indirectly towards the completion of this project

ABSTRACT

Recent advances in the field of power electronic technology and growing and wide-spread uses of nonlinear loads are responsible for the generation of the harmonics in the power system; this significantly degrades the power quality. One of the most common methods to reduce harmonic distortion is to use the passive filters. The objective of this research is to develop a system with three-phase uncontrolled rectifier for harmonic analysis and to design an optimal harmonic passive filter. Since the applications of “artificial intelligence” has been increased to find the practical solutions for the recent developments in engineering and technology. Therefore, it has been decided to apply genetic algorithm for the optimization of passive filter design. In order to fulfil the objectives, optimum passive power filters are designed using MATLAB software. The optimal filter improves the system performance by reducing the harmonic distortion which complies with the standard limits.

ABSTRAK

Kemajuan terkini dalam bidang teknologi elektronik kuasa dan penggunaan lebih banyak beban tidak linear menyumbang kepada penjanaan harmonik dalam sistem kuasa; ini dengan ketara merendahkan kualiti kuasa. Salah satu kaedah yang paling biasa untuk mengurangkan herotan harmonik adalah dengan menggunakan penapis pasif. Objektif kajian ini adalah untuk membangunkan satu sistem tiga fasa penerus terkawal bertujuan untuk menganalisa harmonik dan untuk merekabentuk penapis harmonik pasif yang optimum. Kemajuan aplikasi "kepintaran buatan" telah menyumbang kepada penyelesaian yang praktikal dalam perkembangan terkini bidang kejuruteraan dan teknologi. Oleh itu, algoritma genetik telah digunakan untuk pengoptimuman rekabentuk penapis pasif. Dalam usaha untuk memenuhi objektif, penapis kuasa pasif yang optimum direkabentuk dengan menggunakan perisian MATLAB. Penapis optimum dapat meningkatkan prestasi sistem dengan mengurangkan herotan harmonik yang mematuhi had piawai.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AC	-	Alternating Current
BJT	-	Bipolar Junction Transistor
DC	-	Direct Current
DSP	-	Digital Signal Processing
EMI	-	Electromagnetic Interference
FET	-	Field effect Transistor
GA	-	Genetic Algorithm
HPF	-	Hybrid Passive Filter
HVDC	-	High Voltage Direct Current
MOSFET	-	Metal Oxide Semiconductor Field effect Transistor
PCC	-	Point of Common Coupling
PCs	-	Personal Computers
PPF	-	Passive Power Filters
PSO	-	Particle Swarm Algorithm
PWM	-	Pulse Width Modulation
SVC	-	Static Var Compensator
TCR	-	Thyristor Controlled Reactor
TDD	-	Total Demand Distortion
THD	-	Total Harmonic Distortion
THDi	-	Total Harmonic Distortion in Current
THDv	-	Total Harmonic Distortion in Voltage
UPS	-	UninterrupTable Power Supply

LIST OF APPENDIX

CHAPTER 1

INTRODUCTION

1.1 Project Background

Our modern civilization is very closely related to utilization of the electrical power served by the generation, transmission and distribution. For the proper system performance, it is imperative to ensure that the system voltages and currents that are perfectly sinusoidal in nature. When the loads consisting of inductances, capacitances and resistances are combined in such a way that sine wave is preserved then the load is said to be linear. On the other hand when various loads are conected in such a way that sin wave is not preserved then the load is said to be a nonlinear load. When the nonlinear loads is connected to the mains, the fundamental sinusoidal characteristics of current will be affected [1]. Thus wide-spread and increasing the usage of the power electronic devices like personal computers, uninterruptable power supply systems (UPS), industrial process controls etc. These non-linear loads draw the distorted voltages and currents that contain the harmonics, from the mains. The equipment that cause the harmonics can be found at various locations from office buildings to the manufacturing industries and cannot be ignored in daily life. The devices that can inject the harmonics in power system include the following:

- Personal computers (PCs)
- Variable and adjustable speed drives
- Electronic lighting ballasts

- Uninterruptable power supply (UPS) systems
- Industrial process controls
- Electronic household appliances
- Medical equipment

1.2 Problem Statement

The harmonics due to increased use of nonlinear loads, are the major sources responsible for poor power quality. Power quality can be defined as the "fitness level of the power that is delivered to the consumers from the main supply under some limitations of voltages, currents and frequency for the proper working of the power system devices". The electrical energy supplied to the consumers must satisfy the proper power quality requirements. If the harmonics are not controlled then they can impact adversely on the normal operation of a distribution power system [2] like they can cause the following:

- Electromagnetic interference to neighbouring communication lines
- Increase power loss
- Shutdowns
- Capacitor failures
- Shortening life span of electrical insulation
- Malfunctioning of the sensitive equipment
- Overheating of the transformer
- Harmonic resonance
- System voltage dips
- AC/DC drives failure

- False tripping of protective relays
- Vibration of rotating machines
- Degradation of Voltage quality
- Malfunctioning of medical equipment
- Overheating of neutral conductors

Every power system device has its own capability to tolerate some amount harmonic current but it is needed to protect the power system devices from excessive amount of harmonic current to avoid the malfunctioning of the device. The most common method for mitigating the harmonics is by using filters. The filters limit the harmonics up to the value that will be accepted by the power system and will not harm the device. Filters can be largely categorized in three types first the passive filters these filters are designed with the different combinations of Resistors(R), inductors(L) and capacitors(C). The implementation of the passive filters for the practical applications has some drawbacks. The system performance will depends on the supply impedance and these are large in size [3] second the active filters these filters uses the power electronic switches consequently they have limited switching frequency[4] and the third type called hybrid filter that shares the advantages of both types of filters passive and active.[5]

1.3 Importance of the work

This research project is about the harmonic current generation and its control for the distribution network. The distortion of voltage and current waveforms is one of the most important issue that is faced by the electric industry today due to the considerable conversion of electrical power from alternating current to other forms of electricity, useful in many applications. In the distribution network the harmonic problem occurs only due to the increase of non-linear loads due to the growing use of power electronic devices and the use of microprocessor controllers. Such equipment creates load generated harmonics throughout the system. The generated harmonic currents are responsible to disturb the operation of the supply network and also can damage the electrical equipment including the capacitors installed for power factor correction. Active and passive power filters are the effective equipment to limit the harmonic to the allowable frequency band. At present passive power filters are widely used as compared to the active power filters in many areas due to their lower cost, simple structure, simple working and convenient maintenance [6].

1.4 Objectives of the project

The objectives for this study are as follows.

1. To develop a system with three-phase uncontrolled rectifier for harmonic analysis.
2. To design passive power filter for harmonic reduction.
3. To optimize the filter design using genetic algorithm.

1.5 Scope of the work

In this project passive power filters will be are investigated and analysed for the mitigation of the harmonics developed in a three phase distribution network feeding by nonlinear loads. Passive power filtering method is preferred because passive power filters are simpler and cheaper than active power filters and also provide an effective way to reduce the voltage and current harmonics. Unlike the active power filters passive power filters not only reduce the harmonics but it can also be used for the compensation of the reactive power at the fundamental frequency. The nonlinear load is represented by a three phase uncontrolled rectifier. This type of nonlinear load has wide applications in a distribution system as well as in industries for the conversion of AC to DC power. Three phase six-pulse rectifier is chosen because for industrial applications it is required to have less DC ripple voltage and more power handling capability that can be provided by the three phase six pulse rectifier. Optimization technique is used to get the optimum filter design.

1.6 Methodology

For this project a three phase network with a nonlinear load is simulated using MATLAB Simulink than the harmonics at the point of common coupling will be analysed. Then the harmonic distortion indices i.e. THDi and THDv will be compared with the standards. Since the presence of nonlinear load will cause high harmonics to flow through the network, so for the mitigation of these harmonics passive power filter will be designed and then will be optimized using genetic algorithm the code for the genetic algorithm will be implemented using MATLAB m file.

1.7 Thesis Organization

Chapter 1: this chapter discusses about the background and the general idea about the proposed work. The objectives, importance and scope is also discussed in chapter one.

Chapter 2: This chapter contains the literature review including the previous research about the passive power filters, types of the filter, types of harmonics, basic terminologies about filters, harmonic indices and general procedure about genetic optimization algorithm.

Chapter 3: This chapter is about the methodology followed by this project, starting from the basics of single tuned filters, the procedure to design the single tuned filters and at the end of this chapter optimization procedure for the single tuned passive power filters will be described using genetic optimization algorithm.

Chapter 4: This chapter discusses the results before and after the filtration of the harmonics due to three phase uncontrolled rectifier. Harmonic indices including THD_v and THD_i and the power factor will compared before and after the application of optimum filters.

Chapter 5: This Chapter will concludes the work and will recommend the future work for harmonic mitigation.

REFERENCES

1. a Priyadharshini, N. Devarajan, a R. Uma, and R. Anitt, “Survey of Harmonics in Non Linear Loads,” *Int. J. Recent Technol. Eng.*, vol. 1, no. 1, pp. 92–97, 2012.
2. S. S. Patnaik and A. K. Panda, “Optimizing current harmonics compensation in three-phase power systems with an Enhanced Bacterial foraging approach,” *Int. J. Electr. Power Energy Syst.*, vol. 61, pp. 386–398, Oct. 2014.
3. P. Karuppanan and K. K. Mahapatra, “Active harmonic current compensation to enhance power quality,” *Int. J. Electr. Power Energy Syst.*, vol. 62, pp. 144–151, Nov. 2014.
4. G. Rizk, S. Salameh, H. Y. Kanaan, and E. a. Rachid, “Design of passive power filters for a three-phase semi-controlled rectifier with typical loads,” *2014 9th IEEE Conf. Ind. Electron. Appl.*, pp. 590–595, Jun. 2014.
5. F. Peng, “Harmonic sources and filtering approaches,” *Ind. Appl. Mag. IEEE*, pp. 448–455, 2001.
6. Z. Juan, G. Yi-nan, and Z. Shu-ying, “Optimal design of passive power filters of an asymmetrical system based on genetic algorithm,” *Procedia Earth Planet. Sci.*, vol. 1, no. 1, pp. 1440–1447, Sep. 2009.
7. H. Farooq, C. Zhou, and M. Farrag, “Analyzing the Harmonic Distortion in a Distribution System Caused by the Non-Linear Residential Loads,” *Int. J. Smart Grid Clean Energy*, vol. 2, no. 1, 2013.
8. Y. P. Obulesu, M. Venkateswara Reddy, and Y. Kusumalatha, “A %THD analysis of industrial power distribution systems with active power filter-case studies,” *Int. J. Electr. Power Energy Syst.*, vol. 60, pp. 107–120, Sep. 2014.
9. “Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems,” *IEEE Stand. 519-1992*, 1993.
10. H. Akagi, “Modern active filters and traditional passive filters,” *Bull. Polish Acad. Sci. Tech. …*, vol. 54, no. 3, 2006.

11. Y. Chang and C. Wu, “Optimal Multiobjective Planning of Large-Scale Passive Harmonic Filters Using Hybrid Differential,” *Power Deliv. IEEE Trans.*, vol. 20, no. 1, pp. 408–416, 2005.
12. J. Muhlethaler, “Optimal design of LCL harmonic filters for three-phase PFC rectifiers,” *Power Electron. …*, vol. 28, no. 7, pp. 3114–3125, 2013.
13. R. Mahanty, “Indirect current controlled shunt active power filter for power quality improvement,” *Int. J. Electr. Power Energy Syst.*, vol. 62, pp. 441–449, Nov. 2014.
14. M. A. Mulla, R. Chudamani, and A. Chowdhury, “A novel control method for series hybrid active power filter working under unbalanced supply conditions,” *Int. J. Electr. Power Energy Syst.*, vol. 64, pp. 328–339, Jan. 2015.
15. Z. Xiao-rong and S. Xin-chun, “Simulated annealing based multi-object optimal planning of passive power filters,” in *2005 IEEE/PEC Transmission and Distribution Conference and Exhibition: Asia and Pacific*, 2005, pp. 1–5.
16. G. Panda, P. Kumar, P. S. Puhan, and S. K. Dash, “Novel schemes used for estimation of power system harmonics and their elimination in a three-phase distribution system,” *Int. J. Electr. Power Energy Syst.*, vol. 53, pp. 842–856, 2013.
17. D. Bhonsle and R. Kelkar, “Harmonic pollution survey and simulation of passive filter using MATLAB,” *Int. Conf. Recent Adv. Electr. Electron. Control Eng.*, vol. 1, no. 2, pp. 230–236, Dec. 2011.
18. V. Pandi, H. Zeineldin, and W. Xiao, “Passive harmonic filter planning to overcome power quality issues in radial distribution systems,” *Power Energy Soc. …*, pp. 1–6, Jul. 2012.
19. P. Aravena, V. P. Inst, B. Virginia, and J. Dixon, “Analysis and Design of Multi-Stage Passive Filters for 100 MVA Industrial Power Converters Luis Monin Rolando Burgos,” in *Industry Applications Society Annual Meeting, 2013 IEEE*, 2013, pp. 1–7.
20. J. Ji, G. Zeng, and H. Liu, “Research on selection method of Passive Power Filter topologies,” *Power Electron. …*, vol. 2, no. c, pp. 2844–2848, Jun. 2012.
21. Y. Guo, J. Zhou, J. Cheng, and X. Jiang, “Optimal Design of Passive Power Filters Based on Knowledge-based Chaotic Evolutionary Algorithm,” *Nat. Comput. 2008. …*, pp. 535–539, 2008.

22. A. Dastfan, H. Yassami, and M. Raza Rafiei, "Optimum Design of Passive Harmonic Filter by using game theory concepts," *Intell. Syst. Electr. Eng.*, no. 4, pp. 13–22, 2014.

23. M. Mohammadi, "Bacterial foraging optimization and adaptive version for economically optimum sitting, sizing and harmonic tuning orders setting of LC harmonic passive power filters in radial distribution systems with linear and nonlinear loads," *Appl. Soft Comput.*, vol. 29, pp. 345–356, 2015.

24. Y. P. Chang and C. Low, "An ant direction hybrid differential evolution heuristic for the large-scale passive harmonic filters planning problem," *Expert Syst. Appl.*, vol. 35, no. 3, pp. 894–904, 2008.

25. Y. P. Chang, "Integration of SQP and PSO for optimal planning of harmonic filters," *Expert Syst. Appl.*, vol. 37, no. 3, pp. 2522–2530, 2010.

26. R. Klempka, "Passive Power Filter Design Using Genetic Algorithm," no. 5, pp. 294–301, 2013.

27. K. K. Srivastava, S. Shakil, and A. V. Pandey, "Harmonics & Its Mitigation Technique by Passive Shunt Filter," *Int. J. Soft Comput. Eng.*, vol. 3, no. 2, pp. 325–331, 2013.

28. N. He, L. Huang, J. Wu, and D. Xu, "Study on optimal design method for passive power filters set at high voltage bus considering many practical aspects," *Conf. Proc. - IEEE Appl. Power Electron. Conf. Expo. - APEC*, no. 1, pp. 396–401, 2008.

29. G. Rizk, S. Salameh, H. Y. Kanaan, and E. A. Rachid, "Design of Passive Power Filters for a Three-Phase Semi-Controlled Rectifier with Typical Loads," in *IEEE 9th Conference on lndustrial Electronics and Applications*, 2014, pp. 0–5.

30. a. a A. El-Ela, S. Allam, and H. El-Arwash, "An optimal design of single tuned filter in distribution systems," *Electr. Power Syst. Res.*, vol. 78, no. 6, pp. 967–974, 2008.

31. Y. P. Chang, C. Low, and S. Y. Hung, "Integrated feasible direction method and genetic algorithm for optimal planning of harmonic filters with uncertainty conditions," *Expert Syst. Appl.*, vol. 36, no. 2 PART 2, pp. 3946–3955, 2009.

32. W. Li, Y. Man, and G. Li, “Optimal parameter design of input filters for general purpose inverter based on genetic algorithm,” *Appl. Math. Comput.*, vol. 205, no. 2, pp. 697–705, 2008.

33. S. S. Patnaik and a K. Panda, “Real-time performance analysis and comparison of various control schemes for particle swarm optimization-based shunt active power filters,” *Int. J. Electr. Power Energy Syst.*, vol. 52, no. 1, pp. 185–197, 2013.

34. J. Yu, S. Ding, Y. Wang, W. Wu, and M. Dong, “The engineering design and optimization of main circuit for hybrid active power filter,” *Int. J. Electr. Power Energy Syst.*, vol. 46, pp. 40–48, 2013.

35. M. M. Ertay, “Simulated Annealing Based Passive Power Filter Design for a Medium Voltage Power System,” in *Simulated annealing based passive power filter design for a medium voltage power system*, 2012, pp. 1–5.